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FISH MORTALITY RESULTING FROM DELAYED EFFECTS OF FIRE IN THE GREATER YELLOWSTONE ECOSYSTEM

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Often public concern focuses on the immediate, terrestrial impacts of wildfire. Such was the case during the summer and fall of 1988 when fires burned 562,000 ha in the Greater Yellowstone Ecosystem (GYE; Christensen et al. 1989, Schullery 1989). Besides the obvious loss of vegetation, less apparent, short-term consequences of these fires to terrestrial ecosystems included greater nutrient availability, widespread soil modification, and direct and indirect mortality of wildlife (Christensen et al. 1989, Singer et al. 1989). But as a result of the linkages between streams and their valleys (Hynes 1975), fires also may affect the hydrology, water chemistry, and geomorphology of aquatic ecosystems (Tiedemann et al. 1979, Schindler et al. 1980, Minshall et al. 1989). One consequence of fire is that bed- and suspended-sediment loads are often abnormally high in streams after storm events (Minshall and Brock 1991). Depending on the concentration and duration of exposure, suspended sediment can induce physiological stress, reduce growth, and cause direct mortality in fish (Newcombe and MacDonald 1991). However, as terrestrial vegetation recovers and soils stabilize, concentrations of suspended sediment in streams are expected to decline (Minshall et al. 1989). Unfortunately, little else is known about relations between watershed recovery and aquatic ecosystems following fire.

During the 1988 fires in the GYE, Minshall et al. (1989) observed fish kills in streams, but the extent and causes of mortality were not reported. While conducting other studies of watersheds in the GYE, we observed a fish kill in a burned watershed that occurred two years after the fires. In this paper we describe aspects of this fish kill and relate them to hydrologic conditions in this stream and those in a nearby stream with an unburned watershed.

Study Area

We studied two tributaries of the North Fork Shoshone River in the North Absaroka Wilderness Area adjacent to the eastern border of Yellowstone National Park in the Absaroka Mountains of northwestern Wyoming. Jones Creek drains a 6423-ha watershed that was almost completely burned in 1988. Because of steep topography, drainage comprises numerous high-gradient tributaries and steep ephemeral chutes. The 4946-ha Crow Creek watershed is the next drainage south of Jones Creek watershed, has similar topographic relief and watershed orientation, and still supports extensive mixed-age stands of conifers. Both watersheds consist of geologically young and highly erodible volcanic soils (Minshall and Brock 1991).

Methods

On 17 and 18 August 1990 we surveyed 1774 m of the stream channel and lower and upper banks of Jones Creek for dead fish following storm flows that had been caused by rain that began at 1600 hours on 16 August. Fish were identified, measured, and examined to determine possible causes of death. We examined the external anatomy of the fish, including skin, eyes, and gills, as well as stomachs of several fish.

Suspended sediment and discharge data from April to September 1990 were obtained

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from continuous remote sampling stations operated by the U.S. Geological Survey (USGS 1990). Suspended sediment concentrations are daily means based on 2–4 samples per day; mean daily discharge was based on hourly observations. On 17 August we collected two grab samples from Jones Creek to quantitatively assess the unusually high concentration of suspended sediment observed during the storm. Samples were collected at mid-depth in 0.5 m of water. We analyzed the grab samples for total suspended sediment by filtering them through Whatman grade 934AH fiberglass filters (1.5 μm effective pore size), oven-drying them for 1 week to constant weight, and then measuring them and averaging the results to determine the total concentration of suspended sediment (APHA 1989).

RESULTS AND DISCUSSION

On 17 and 18 August 1990, 1 rainbow trout (*Oncorhynchus mykiss*), 4 Yellowstone cutthroat trout (*O. clarki bouvieri*), 11 brook trout (*Salvelinus fontinalis*), and 2 Yellowstone cutthroat trout × rainbow trout hybrids, all ranging from 190 to 410 mm total length, were found dead during surveys of Jones Creek. We found fish only in or near obstructions to flow (e.g., debris accumulations and boulders); thus, our survey probably overlooked dead fish that had been transported downstream or buried in newly formed bars. We believe that fish collected on 17 August had died recently because rigor mortis had not set in. Fish collected the following day were rigid and had started to dry; we suspect these also had succumbed on 17 August. Surveys on seven other occasions on Jones Creek (including 16 August) and eight other occasions on Crow Creek failed to reveal any moribund fish.

Each fish we examined appeared to have been asphyxiated by sediment. Typically, sediment completely embedded the gills of each fish, and individual lamellae often were difficult to see (cf. Cordone and Kelley 1961: 192). Eyes and skin appeared to be relatively normal, and fish lacked contusions and lacerations. Stomachs we examined appeared normal, and all contained recently consumed invertebrates.

Timing of the fish kill coincided with storms that began on 16 August and continued into the early morning of 17 August. Nearly 2.3 cm of rain was recorded on 16 August, followed by an additional 0.7 cm the next day. Though discharge in Jones Creek peaked on 16 August, concentration of suspended sediment did not appear to peak until 17 August (Fig. 1). And though suspended sediment concentrations on 17 August were the highest recorded from April to September 1990 (USGS 1990), concentration of suspended sediment in grab samples (9680 mg/L) was more than an order of magnitude higher than the daily mean concentration (587 mg/L) recorded for that date. Because the continuous remote sampling station collects samples at intervals, it is likely that the automated sampling missed the instantaneous peak concentration of suspended sediment. Likewise, it also is possible that our grab samples did not represent the instantaneous peak concentration.

Suspended sediment is known to be lethal to salmonids, but usually at higher concentrations and/or for longer exposures (Redding et al. 1987, Newcombe and MacDonald 1991) than we observed in Jones Creek. For example, Newcomb and Flagg (1983) calculated that a 36-h exposure to a suspended sediment concentration of 9400 mg/L would kill 50% of juvenile chinook salmon (*O. tshawytscha*) and sockeye salmon (*O. nerka*). However, lethal effects of suspended sediment may be more pronounced in the field than in the laboratory. In live-box tests in streams affected by ashfall from Mount St. Helens, concentrations of suspended sediment as low as 488 mg/L killed 50% of chinook salmon smolts after a 96-h exposure (Stober et al. 1981). But in comparable laboratory tests, a concentration of 19,364 mg/L was required to produce the same mortality rate (Stober et al. 1981). Clearly, suspended sediment concentrations in Jones Creek were stressful for trout. For the 24 h beginning at 1600 on 16 August, we estimated a minimum stress index of 11.3 $mg \cdot h \cdot L^{-1}$ (Newcombe and MacDonald 1991), which is near the value associated with lethality in adult salmonids (12 $mg \cdot h \cdot L^{-1}$; C. P. Newcombe personal communication).

Other factors may have contributed to the fish kill in Jones Creek. Newcombe and MacDonald (1991) and C. P. Newcombe (personal communication) suggested that high or fluctuating temperatures may increase the sensitivity

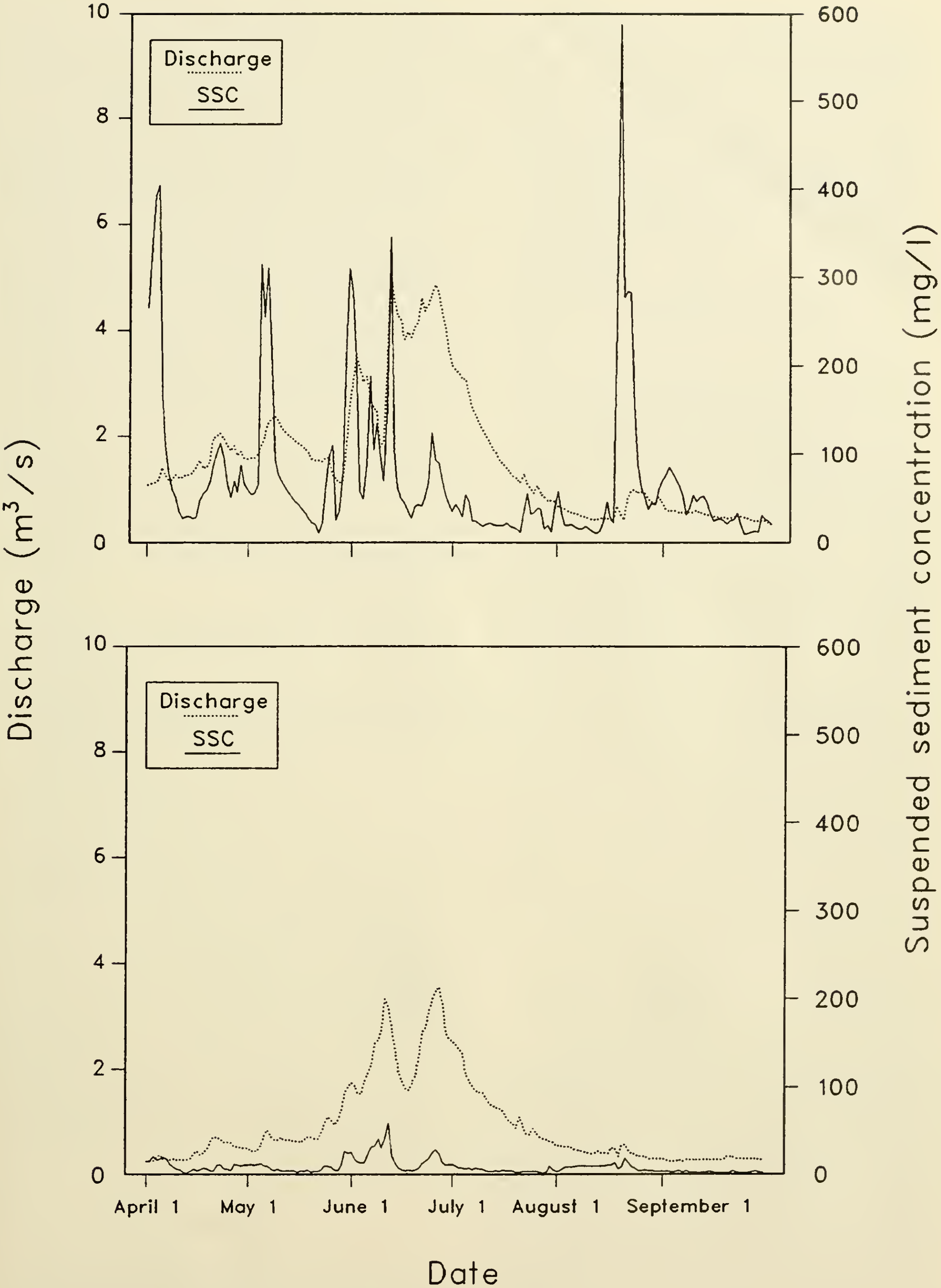

Fig. 1. Discharge and suspended sediment concentrations from April through September 1989 in Jones Creek (above) and Crow Creek (below), Wyoming (USGS 1990). The peak in suspended sediment in Jones Creek on 17 August coincides with the fish kill.

of trout to suspended sediment. In Jones Creek, water temperature varied from 10.1 to 17.3°C on 17 August (USGS 1990), but this fluctuation was equaled or exceeded on 70 of the 137 monitored days. Furthermore, these temperatures are largely within the range of those reported from other tests (e.g., Newcomb and Flagg 1983, 15–17°C; Redding et al. 1987, 12.5–13.5°C). A reduction in dissolved oxygen concurrent with peak suspended sediment concentrations, or other changes in water chemistry, may also have contributed to mortality, but we did not measure these parameters.

Tiedemann et al. (1979) indicated that landslide activity in steep drainages increases after wildfires. In Jones Creek a debris torrent down a tributary, apparently caused by heavy rainfall on unstable burned slopes, may have produced the high concentrations of suspended sediment on 17 August. After surveying farther upstream on subsequent days, we found a fresh debris and mud jam in Jones Creek near the mouth of a severely eroded tributary. Possibly because the stream was downcutting through this material, concentrations of suspended sediment remained high for several days (Fig. 1). Once activated by rainfall, numerous other ephemeral channels also carried silt-laden water for several days, but in concentrations visibly less than the peak concentration observed in Jones Creek.

The effects of fires on streams include increases in discharge and suspended sediment (Tiedemann et al. 1979, Schindler et al. 1980), and these differences seem evident in the comparison between the burned Jones Creek and the unburned Crow Creek watersheds. Discharge and suspended solid concentrations in Jones Creek were relatively high and erratic throughout the 137-day sampling period (Fig. 1). During this time the daily mean concentration of suspended sediment averaged 73.9 mg/L (USGS 1990). Though concentrations of total suspended sediment often increased with stream discharge (e.g., during spring runoff), pronounced episodic peaks in the concentration of suspended sediment also occurred during lower discharges, apparently associated with summer rainfall (e.g., as seen 16–21 August).

In contrast, discharge and suspended solid concentrations in the unburned Crow Creek watershed were markedly lower and more stable (Fig. 1). As in Jones Creek, suspended sediment increased during snowmelt and storm events, but changes appeared more proportional to increases in discharge. Daily mean concentrations of suspended sediment averaged 8.2 mg/L; the maximum daily mean concentration recorded (59 mg/L) was less than the Jones Creek average for the entire sampling period. Unfortunately, though the contrast between responses of both watersheds was quite marked, the lack of pre-fire hydrologic data makes it difficult to conclude that this contrast was the result of fire. However, during observations made on both streams for 4 weeks over 2 years, we did not witness similar concentrations of suspended sediment or a fish kill in either stream. At least circumstantially, the fish kill appears to be related to the unusually large hydrologic event associated with a rainstorm in the Jones Creek watershed.

The fish kill that we observed was notable because it occurred 2 years after the fire and appeared to result from an acute exposure to sediment. The extent and frequency of lethally acute concentrations of suspended sediment, as well as their effect on entire fish populations, are unknown. Previous fires in the Yellowstone area in the 1700s were at least as intense as those that occurred in 1988 (Romme and Despain 1989) and may also have produced slope instability, high suspended sediment concentrations, and, consequently, fish kills. In both Jones and Crow creeks we found remnants of the toes of landslides and the termini of debris flows that may have resulted from past fires. Because fire is a natural disturbance that will recur, further investigations are needed to gain a better understanding of the effects of fire and how watersheds, streams, and fish populations respond immediately and during the successional recovery of adjacent terrestrial vegetation.

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